North Twenty-First Street Bridge
(Buckley Gulch Bridge)
(North Twenty-First Street Viaduct)
Spanning Buckley Gulch on North 21st Street
Tacoma
Pierce County
Washington

HAER No. WA-83

HAER
WASH
27-TACO,
10-

PHOTOGRAPHS

WRITTEN HISTORICAL AND DESCRIPTIVE DATA

Historic American Engineering Record
Western Regional Office
National Park Service
U.S. Department of the Interior
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HISTORIC AMERICAN ENGINEERING RECORD

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North Twenty-First Street Bridge
(Buckley Gulch Bridge)
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HAER No. WA-83

Location: Spanning Buckley Gulch on North 21st Street between North Fife Street and Oakes Street, Tacoma, Pierce County, Washington

UTM: 10.540120.5234800

Date of Construction: 1910-1911. Altered in 1939. Other alteration dates are unknown.

Engineer: Waddell and Harrington, Kansas City, Missouri

Builder: Creelman, Putnam and Healey, Tacoma, Washington

Present Owner: City of Tacoma, Washington

Present Use: Vehicular bridge (to be replaced)

Significance: The North Twenty-First Street Bridge is one of the earliest examples of a continuous reinforced concrete girder bridge constructed in the United States. It was designed by the firm of Waddell and Harrington in 1910 and completed in 1911. The four continuous rectangular girders span a total of 180" (three spans of 60' each). They are supported on gravity abutments and eight separate rectangular reinforced concrete piers (two piers per girder).

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Physical Description

The bridge that crosses Buckley Gulch on North Twenty-First Street is technically a viaduct, described by J. A. L. Waddell, the bridge's designer, as a structure carrying a highway over a dry gulch. Charles Fowler defined a viaduct as a bridge in which a series of spans are born on individual towers composed of two or more bents braced together. Meeting the definition of both authors, the viaduct is located on North Twenty-First Street, between North Oakes and Fife streets, and is generally situated in an east-to-west direction. The area is primarily residential in nature, with close proximity to the University of Puget Sound (UPS). A few small commercial businesses are located immediately west of the bridge. When the North Twenty-First Street Bridge was constructed, Buckley Gulch was relatively free of vegetation except for low ground cover. The tall deciduous trees present today, predominantly maples and cottonwoods, have grown up over the last eighty years [see HAER photographs no. WA-83-1 and WA-83-2]. At the time of construction, Buckley Gulch was approximately 60' deep at the structure's midpoint. It is now approximately 50' deep, due to miscellaneous dumping and infill over the years. The gulch has also had its overall shape changed slightly by infill at either end.

The roadway alignment of the viaduct is straight and the grade is flat. The approach from the west side is generally described as flat, sloping very gently down as it crosses Oakes Street [see HAER photograph no. WA-83-3]. The east approach has a much greater downward slope, that flattens out at the easterly edge of the bridge (see HAER photograph no. WA-83-4].

The viaduct roadway is 48' wide, curb to curb, with 6' sidewalks cantilevered from each side, creating a total width of 60'. The present roadway width provides for two driving lanes down the center of the structure, with one lane of parking on each side. Originally, the viaduct carried two sets of streetcar tracks down the center, spaced 12' apart (they were removed in 1939). The original drawings indicate a 1' 6" wide brick gutter at the outer edges of the roadway that have now been removed or covered over [see HAER photograph no. WA-83-17, Sheet no. 2].

The viaduct is 180' long (excluding the approaches) and is in three equal spans. It extends from abutment to abutment and is continuous across the concrete bents. The abutments are constructed of reinforced concrete and each has four projecting reinforced haunches that extend out to support the main girders [see HAER photograph no. WA-83-12]. Each abutment retains fill for the approaches at either end of the viaduct. Original designs for the abutments indicated 5:12 battered sidewalls on the north and south sides of the abutments [see HAER photograph no. WA-83-20, Sheet No. 5]. During construction, the design for the west abutment battered sidewall sections was modified slightly to extend the sidewalls back into the hillside. The vertical sidewalls sections at the west abutment extend back approximately 68' into the hillside. The abutment on the east side of the viaduct was constructed as originally designed, except that the sidewall design was modified to extend back approximately 34' into the hillside. There is an expansion joint on the west side of the viaduct, at the location of the abutment below [see HAER photograph no. WA-83-8].

The asphalt roadway surface has 6" crown and is supported on a 6" unreinforced concrete slab over a slab or gravel ballast cushion. The sand layer is supported on an 8-1/2" reinforced concrete slab that is integrally cast with the longitudinal girders. Transverse beams cantilever out from beneath the deck surface to support the structure's sidewalks and handrails [see HAER photographs no. WA-83-5, WA-83-17, Sheet no. 2, and WA-83-18, Sheet no. 3].

The handrail sections are also constructed of reinforced concrete. The rail is approximately 4' above the concrete-wearing surface of the sidewalk and is divided into twenty-eight panels on the south side and twenty-two panels on the north side. Each panel is approximately 6' 6" wide and is made up of six vertical concrete balusters [see HAER photograph no. WA-83-6]. The panels are separated by intermediate concrete posts that are 12" square and have a top that is flush with the top rail [see HAER photograph no. WA-83-7]. Each end of the handrail was originally terminated with a post of larger dimension (18" square). Only the posts on the west side of the viaduct remain [see HAER photograph no. WA-83-9]. The endposts on the east side have been removed and replaced with sections of painted pipe railing [see HAER photograph no. WA-83-4]. Every fourth post was designed to accept a cast-iron light standard and is fitted with 4'6" long x 1/2" diameter bolts to attach to the lamp posts. A 15" cantilevered knee brace is centered below each post on the outboard side of the sidewalk. Below the two posts originally designed to carry the trolley poles, the knee brace is 18" wide. On each handrail, the original two-piece chamfered rail cap and stepped post caps have been replaced with a continuous concrete cap that extends the full length of the structure. The top rail no longer has the modulation that had been originally provided by the individual post caps [see HAER photographs no. WA-83-15, WA-83-17, Sheet no. 2, and WA-83-18, Sheet no. 3]. The bridge plates that were once attached to the remaining west endposts are missing [see HAER photograph No. WA-83-9].

The primary structure of the viaduct is a rigid frame of continuous, horizontal, rectangular girders and rectangular vertical bents. Below the roadway level, the four main girders are supported on two bents of four concrete piers each (eight columns total). The piers are visually connected to the girders at the outside edges by diagonal fillets on each side (see HAER photograph no. WA-83-10). Each bent is composed of two outer piers, 4'0" x 3'6" and two inner piers, 7'6" x 3'6". The two inner piers are spaced at 12'0", center to center, and are carried on a below-grade intermediate footing plinth. The outer piers are 16'6" further to the outside and have separate footing plinths. All of the plinths are connected below grade to continuous spread footing that is 28' wide and 3' deep. The four piers of each bent are connected at the top with a 9' deep x 3'6" wide cross girder. The cross girder is visually connected to each pier on the interior surfaces by a diagonal fillet similar to those at the top of the outer piers [see HAER photographs no. WA-83-11, WA-83-13, and WA-83-16, Sheet no. 1].

The four main girders are 9' in depth and are supported at third points on the two bents. The two inner girders are 6'6" wide and were located directly below the two sets of steel trolley lines, at 12'0", center to center. The two outer girders are slightly narrower in width, 4'0", and are located 16'6" outboard of the inner girders. The configuration of the reinforcing steel in the girders provided for continuity over the column supports, as well as utilizing diagonal and bent up bars to resist diagonal tension stresses in the concrete. Multiple layers of reinforcing steel were also uniquely utilized in the top and bottom zones of the girders [see HAER Photograph no. WA-83-19, Sheet no. 4]. The roadway slab is secondarily supported below by intermediate cross girders, 1'6" deep x 1'3" wide and spaced at 7'6", center to center. On the north side of the bridge, several pipes (water and gas) are supported on intermediate cross girders, 8" wide x 13" deep, installed at 10'0", center to center. These cross girders are located between the inner and outer girder beams of the structure's north side and are set approximately 1' above the underside of the beams. As noted on the original drawings, all exposed corners of all girders and cantilevers are chamfered - the main girders have a 2" chamfer; all others are 1-1/2".

Current Condition[1]

Visually, the North Twenty-First Street Bridge is in fair condition, but shows signs of cracking, water seepage, and evidence of past patching and restoration. The concrete has darkened with age and environmentaL contaminants. Moss and dirt have accumulated at the railing intersections. There are substantial areas of deteriorated concrete, where the surface is cracked and spalled and the reinforcing steel is exposed and corroded beyond usefulness.

Below the bridge surface, the inner girders show evidence of minor spalling and the outer girders exhibit water damage from weather exposure and water seepage from above. At the underside of the cantilevered sidewalk sections, there are areas of water staining and where the gridwork of the reinforcing is readily visible. The outer surface of the cantilevered sidewalk brackets and the exposed slab edges are deteriorated. The 1989 C3R Report by Entranco Engineers indicates that a major portion of the deterioration is caused by carbonation, the reduction of concrete alkalinity as a result of harsh environmental conditions such as carbon dioxide and other acidic gases.

The viaduct abutments show some signs of spalling and cracking at cold joints, but are generally in fair condition. The eight columns exhibit evidence of past patching and restorative work. The pier at the northeast side is completely buried by backfill from an adjacent parking lot [see HAER Photograph no. WA-83-14].

Historical Context

On Sunday, April 2, 1911, the Tacoma Daily Ledger proclaimed that two new bridges, the North Twenty-First Street Bridge and the North Twenty-Third Street Bridge were to be added to the list of concrete achievements in the city of Tacoma. This list of concrete achievements included such structures as the high school stadium, the National Realty Building, the Northern Pacific Car Shops, and the Union Station. The "two handsome spans" were to be pointed out to visitors to the area as the newest in structural achievements.[2] Ironically, in the 1990s, the North Twenty-First Street Bridge is traveled virtually unnoticed and is in need of repair. The North Twenty-Third Street Bridge is presently undergoing renovation and will be reopened only to pedestrian traffic.

The two spans are almost identical in design; stark, geometric forms of reinforced concrete, both spanning Buckley Gulch, located in the north-end residential neighborhood of Tacoma, near Old Town. The North Twenty-First Street Bridge is the shortest of the two, but was designed to carry heavier loads - automobile and trolley traffic. The North Twenty-Third Street Bridge was designed for "pedestrians, team and automobile traffic." When they were constructed, between 1910 and 1912, the structures altered the appearance of the gulch, which was barren of the tall trees present today and was spanned by one "rickety frame trestle." Although adjacent property owners desired more traditional arched structures to span the gulch, the sides of the ravine were of sandy soils incapable of accommodating the massive thrust that an arch would impose.[3] It was possible the surrounding soil conditions that prompted the progressive designs of the new structures.

At the turn of the twentieth century, bridge engineering had progressed a long way from the simple log bridge laid across a stream and from the braced stone arches of the Roman era. Up until the late 1800s, most bridge structures were the work of "low bidders," typically the bridge manufacturers, and were built of predominantly iron or timber. This yielded structures that were obviously lacking in long term rigidity and lateral stability. The spans were modest, but the builders were typically familiar with the concepts.[4] The typical form of the longest spans was the arch, which made the best use of the compressive capabilities of the materials. "Man-made masonry," plain poured concrete, typically composed of a mixture of sand, cement, water and gravel, was treated initially as artificial stone, and was only strong in compression. It was not until the 1870s and the 1880s that concrete was developed as a structural building material. Strangely enough, the concept of reinforcing concrete slurries was invented by Joseph Monier, a French gardener, searching for a way to make bigger flower pots. He discovered he could insert a network of iron wire into wet concrete and produce larger, stronger and less bulky containers.[5] The man-made masonry, previously with only high resistance to compression, was found to exhibit strength in tension and shear through the molding of liquid concrete around iron or steel reinforcing bars. The resultant material had a combined strength much greater than the strengths of the two materials separately, and a plastic quality that was entirely its own, and entirely new.[6]

Up to 1850, the design of bridges in the United States had been results of the builders' judgment and experience, and was concern primarily with the economy of materials and design costs. It was the advancement of the railroad and development of other transportation methods that brought about the development of "engineering" as it is known today. Timber was found to be inadequate for the longer spans and heavier loads imposed by the nation's desire for better and faster means of transportation. Although reinforced concrete as a structural material was introduced into the United States in the middle 1870s, the first application in bridge construction was not until the early 1890s.[7] Its use required in-depth mathematical analyses of construction methods and materials heretofore not applied to bridges. The new material required an expanded knowledge of the laws of mechanics and the properties of materials; as well as an understanding of the use and value of stress calculations. It was the published technical reports on property engineering practice and publications of material test results of the early 1890s that had a profound effect on the production of effectively braced, laterally stable and carefully proportioned bridges by the turn of the twentieth century.[8]

Thus, bridge engineering became a highly specialized field. It was during this period of engineering advancement that the renowned firm of Waddell and Harrington was formed. Their partnership, based in Kansas City, Missouri, was formed in 1906 and lasted eight years. During that time, the firm "developed an exceedingly large and important practice, amounting to one period, simultaneously in office and field, to some fifteen million dollars' worth of bridge work."[9] It is not surprising that when the city of Tacoma had the need for two bridges to span particularly difficult sites that the firm of Waddell and Harrington was hired to design them.

J. A. L. Waddell, in his book Bridge Engineering (published in 1916), stated that the obsolescence and failure of many of the bridges up until the increase in mathematical structures was due to bad design, the lack of understanding of internal material stresses, and the lack of attention to detail and connections. He was also particularly convinced that the advent of reinforced concrete bridge construction would improve the unacceptable state of many of the nation's highway bridges. However, he stated "It requires engineering skill of a higher order and greater practical experience to plan bridges of reinforced concrete than it does...steel structures and...needs much more rigid inspection of materials and workmanship." If properly designed and constructed, concrete bridges would require less maintenance and could last "forever." He pointed out that while reinforced concrete was a new and exciting art, it was not suitable to all conditions and should be used appropriately.[10]

As predicted by Waddell, the use of reinforced concrete in American highway construction became very prevalent in the twentieth century, both in arch and girder construction. Carl Condit points out in his book, American Building Art, 20th Century, that the concrete girder bridge exists in such immense numbers that its occurrence is virtually commonplace, making a selection of significant or noteworthy examples difficult.[11]

The North Twenty-First Street Bridge, designed by Waddell and Harrington in 1910 and completed in 1911, is significant as one of the earliest examples of a reinforced concrete bridge that was not in the shape of the traditional arch or truss. It is a continuous rigid frame horizontal girder bridge utilizing reinforced concrete abutments and bents as supporting members. It is of a relatively simple design that closely follows J. A. L. Waddell's own prescription for the design and construction of reinforce concrete bridges. The key to the success of the use of concrete is the proper distribution of the reinforcement bars. In Volume 2 of his book, he verbally diagrammed a method of girder reinforcement that is almost identical in that shown as the original design drawings. "...the arrangement of the reinforcement in continuous girders requires considerable care...bars bent up from the bottom reinforcement should be used in the reinforcement over the supports as far as possible; and they should be arranged so as to reinforce for diagonal tension in the most effective manner. Bars should be extended some distance past the point where they could theoretically stop, in order to ensure that the bond stresses will be low. This procedure will also keep the unit stresses in the steel low, which will strengthen the girder considerably in diagonal tension...when stirrups are required as web reinforcement, those in the central portion of the girder should be of the type show...; while those in the end portions, where the moment is negative should be similar but inverted."[12]

The girder beams are visually massive and appear almost over-designed (the main girders are 9' deep). However, they conform to Waddell's number one principle, "simplicity...one of the highest attributes of good design."[13] The bridge also adheres to Waddell's basic aesthetic principle that perfect symmetry in layout is the most desirable, even if there is added expense to achieve it. l Outlines should not be monotonously straight, but according to Waddell, it was not permissible to add ornamental details to a bridge that confused the action of the structure or proclaimed a different function.[14] On the North Twenty-First Street Bridge, the diagonal infills at the pier caps serve to establish the proper visual scale and proportion of the pier connections to the girders.

Whereas the bridge structure should never exhibit any unnecessary parts or forms, Waddell felt that the installation of ornamental electric light standards was an acceptable form of ornamentation, and could in fact have a pleasing effect on viaducts especially. Additionally, Waddell felt comfortable prescribing some form of ornamental handrails as long as they were subordinate with the main structure and ended with posts of "dignified size."[15] The open concrete railings of the North Twenty-First Street Bridge, with symmetrically placed vertical balusters, and separately formed top rail and post caps, were ornamented with cast iron electric light standards. One newspaper article quoted W. C. Raleigh, city engineer at the time of construction, as saying one of the "pleasing features of the new bridge is the system of ornamental lamp posts planned set at regular intervals on both sides."[16]

When first completed in 1911, the North Twenty-First Street Bridge carried a double track street railway down the center, and automobile lanes down each side. At the time, North Twenty-First Street served as a main arterial to the north end of Tacoma. The new structure provided continued railway service from the downtown area to northern residential area of the city, as part of the Point Defiance Line. l There was a previous wood trestle across the gulch prior to the construction of the new viaduct.

Access across the gulch was maintained by a temporary wood trestle with an elevated deck, constructed along one side of the new bridge. The "false deck" was utilized by team and streetcar traffic until the roadway was completed. The temporary trestle was constructed to facilitate the switching of the streetcars, as with this method no rerouting was necessary.[17] Waddell, in his book <u>Bridge Engineering</u>, also included a special chapter on the importance of maintaining traffic routes during new bridge construction, and prescribed several methods of achievement.

The North Twenty-First Street Bridge was estimated for completion in January 1911. A newspaper article in April of that year indicated it was almost completed. It was constructed by the Tacoma firm of Creelman, Putman and Healey for a cost of $49,780. Tacoma Railway and Power funded half of the cost of construction. The rest was funded by the city's bridge bond fund.[18] It has been in continuous operation since the time of its completion and currently serves as a principal arterial route, carrying more than 14,000 vehicles per day.[19]

END NOTES

1. A complete investigative and structural analysis was performed by Entranco Engineers in 1989. This report should be consulted for a more indepth condition report.

2. Tacoma Daily Ledger, April 2, 1911, p. 37.

3. Tacoma Daily Ledger, May 15, 1910, p. 47.

4. Chrimes, p. 35.

5. Silverberg, p. 106.

6. Kassler, p. 84.

7. Waddell, p. 28.

8. Ibid., p. 31. The advances in bridge engineering of the early 1900s were being closely paralleled in the field of building construction. l By 1900, reinforced concrete had become an extremely popular building construction material. Ernest L. Ransome, a leading building designer at the time, was successfully utilizing the simple principle of locating reinforcing bars near the undersurface of beams and joists, the region of maximum tension. The number and size of the bars was determined by the loads imposed on a particular member. The forces attributed to shear were determined by the quantity of material in the frame and slabs and by the spacing of the bearing members. (Condit, p. 154).

9. Ibid., p. viii.

10. Ibid., p. 1536.

11. Condit, p. 207.

12. Waddell, p. 936.

13. Ibid., p. 267.

14. Ibid., p. 1160.

15. Ibid., p. 1177.

16. Tacoma Daily Ledger, May 15, 1910, p. 47. The lamp posts were removed sometime after the construction of the bridge.

17. Ibid.

18. Ibid.

19. C3R Analysis, p. 1.

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Tacoma Daily Ledger, "New Gulch Bridges to Take Shape Soon," July 3, 1910, p. 35.

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ORIGINAL DRAWINGS

City of Tacoma Public Works Department Files

Reinforced Concrete Viaduct over Buckley Gulch at North Twenty-First Street, Tacoma, Wash., stamped: Waddell and Harrington Consulting Engineers, Kansas City, Mo.:

* Sheet No. 1	General Layout, 1' = 1'0", dated 5-13-10.
* Sheet No. 2	Typical Cross Section, Detail of Hand Rail, Details of Cross Beams for Pipes, dated 5-13-10.
* Sheet No. 3	Details of Cross Girders and Cantilevers, Details of Columns, Details of Pedestals, 1/4" and 1/2" - 1'0", dated 5-13-10.
* Sheet No. 4	Details of Main Girders, Details of Lamp Posts, Details of Plates, 1/4" and 3/4" = 1'0", dated 5-13-10.
* Sheet No. 5	Details of Abutments, 1/8" = 1'0", dated 5-13-10.
* Sheet No. 6	Sketch of Temporary Trestle, dated 5-13-10.

Reinforced Concrete Viaduct over Buckley Gulch at North Twenty-First Street, Tacoma, Wash., City of Tacoma, Chief Engineers Office:

Sheet No. 5A	Details of Changes in West Abutments, 1/8" = 1'0", dated 6-30-10.
Sheet No. 5B	Details of Changes in East Abutments, 1/8" = 1'0", dated Jan. 1911.

Unnumbered Sheet Plan of North Twenty-First Street Bridge, 1" = 10'0", dated 11-23-09.

* indicates drawings are included in HAER documentation as photographic copies. See Index to Photographs in this documentation.